DIFFRACTIVE DIS FROM THE COLOR DIPOLE BFKL POMERON [1]

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We review the recent progress in the theory of diffractive DIS, focusing on predictions of strong breaking of the Ingelman-Schlein-Regge factorization and the related breaking of the GLDAP evolution for the diffractive structure function.

1 Diffractive DIS and partonic structure of the photon

The microscopic QCD mechanism of diffractive DIS (DDIS) is a grazing, quasielastic scattering of multiparton Fock states of the photon on the target proton, which is best described viewing these Fock states as systems of color dipoles spanned between quarks, antiquarks and gluons [1, 2, 3]. In inclusive DIS, the effect of gluons in the photon is reabsorbed into the Bjorken x dependence of the color dipole cross section $\sigma(x, r)$, which satisfies the running gBFKL equation [3, 4]. In the pQCD domain of small dipoles r

$$\sigma(x, r) = \frac{\pi^2}{3} r^2 \alpha_S(r) G(x, q^2 \approx \frac{10}{r^2}) \tag{1}$$

where $G(x, q^2)$ is the gluon structure function of the target nucleon [5].

A color dipole treatment of DIS comes truly of age in DDIS. The driving term of DDIS is an excitation of the $q\bar{q}$ state for which [2] (we focus on $t = 0$)

$$\frac{d\sigma^D}{dt} = \int dM^2 \frac{d\sigma^D}{dtdM^2} = \frac{1}{16\pi} \int_0^1 dz \int d^2\vec{\rho} |\Psi_{\gamma^*}(Q^2, z, r)|^2 \sigma^2(x_{\mathbf{IP}}, r)\,, \tag{2}$$

where $|\Psi_{\gamma^*}|^2$ is the color dipole distribution in the photon [1]. Eq. (2) and its generalizations to higher Fock states are rigorous field theory results and answer all the pertinent questions [3, 6, 7, 8, 9, 10] : i) how DDIS scales with Q^2? ii) does the partonic structure function of the pomeron make any sense? iii) is DDIS soft or hard process? iv) how to control the hardness of DDIS? v) what is the flavor content of DDIS? vi) what is σ_L/σ_T for DDIS? vii) how inclusive DDIS matches exclusive vector meson production? In our understanding of DDIS we are entering the era of enlightenment, one must focus on adequate Monte Carlo implementation of QCD ideas on DDIS (to be reported at the next DIS workshop?), see Ada Solano's status report at this conference [11].

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2 Poor man's interpretation of diffraction: the Regge factorization

The diffractive structure function is operationally defined as

$$(M^2+Q^2)\frac{d\sigma^D}{dt\,dM^2}=\frac{\sigma_{tot}(pp)}{16\pi}\frac{4\pi^2\alpha_{em}}{Q^2}\left\{F_T^D(x_{\mathbf{I\!P}},\beta,Q^2)+\varepsilon_L F_L^D(x_{\mathbf{I\!P}},\beta,Q^2)\right\}. \quad (3)$$

The variables $\beta=Q^2/(Q^2+M^2)$ and $x_{\mathbf{I\!P}}=(Q^2+M^2)/(Q^2+W^2)=x/\beta$ (we stick to the Eilat convention, ε_L is the longitudinal polarization of the photon) don't tell anything of the interaction mechanism and the words "pomeron exchange" bear no information beyond that the reaction considered is diffractive. Still, the DIS community fell the temptation of endowing the pomeron with the usual attributes of a particle such as the partonic structure functions $F_{T,L}^{\mathbf{I\!P}}(\beta,Q^2)$ and the flux of pomerons $\phi_{\mathbf{I\!P}}(x_{\mathbf{I\!P}})/x_{\mathbf{I\!P}}$ in the proton [12]:

$$F_{T,L}^D(x_{\mathbf{I\!P}},\beta,Q^2)=\phi_{\mathbf{I\!P}}(x_{\mathbf{I\!P}})F_{T,L}^{\mathbf{I\!P}}(\beta,Q^2)\,. \quad (4)$$

3 Diffraction defies the Ingelman-Schlein-Regge factorization, is mostly soft but exhibits the Bjorken scaling

The Ingelman-Schlein-Regge factorization (4) is not borne out by the QCD theory of diffraction, which we always maintained since our 1991 work [2] and demonstrated explicitly in 1994 [6]. First, focus on $q\bar{q}$ excitation. For T photons one finds $d\sigma_T^D/dt\propto G^2(x_{\mathbf{I\!P}},q_T^2\approx m_f^2)/Q^2m_f^2$, which is dominated by the contribution from soft dipoles $r\sim 1/m_f$. Beware of the nonperturbative contributions on top of the perturbative gBFKL pomeron, still the $1/Q^2$ leading twist behavior of σ_T^D is a rigorous result [1, 2], neither the Regge factorization nor the concept of the partonic structure of the pomeron are needed for that! A comparison with (4) implies a plethora of flavor dependent "pomeron flux factors" [7, 8] $\phi_{val}(x_{\mathbf{I\!P}})\propto G^2(x_{\mathbf{I\!P}},q_T^2\approx m_f^2)$, in defiance of the Ingelman-Schlein-Regge factorization. For L photons [2, 9] $\sigma_L^D\propto G^2(x_{\mathbf{I\!P}},q_L^2\approx \frac{1}{4}Q^2)/Q^4$. It is dominated by $r\sim 1/Q$ and has the higher twist behavior. The pQCD scale $q_L^2\approx\frac{1}{4}Q^2\neq q_T^2$, in further defiance of the Ingelman-Schlein-Regge factorization, which must be buried in state.

4 Dijets and more on the factorization breaking

Excitation of the $q\bar{q}$ state gives rise to the back-to-back jets with the transverse momentum $\vec{k}$ with respect to the $\gamma^*\mathbf{I\!P}$ collision axis. The jet cross sections have been derived in [2, 6] in a simple analytic form and elaborated in [8, 9]. One finds $d\sigma_{T,L}^D/dM^2dk^2dt\propto G^2(x_{\mathbf{I\!P}},q_{T,L}^2)$ with the β,k^2 dependent pQCD scale $q_{T,L}^2$ which increases towards $M^2\ll Q^2$ and/or large k^2:

$$q_{T,L}^2=(k^2+m_f^2)(M^2+Q^2)/M^2=(k^2+m_f^2)/(1-\beta) \quad (5)$$

Remarkably, $d\sigma_L \propto 1/k^2$ and σ_L is dominated by large angle jets with $k^2+m_f^2 \approx \frac{1}{4}M^2$. For dijets with $M^2 \gg Q^2$ and real photoproduction see [6]. Bartels reported on similar results [13] which are also based on our technique [6].

5 The valence quarks and gluons and sea of the pomeron

F_T^D for $q\bar{q}$ excitation resembles the valence structure function of hadrons [2, 3, 8]

$$F_T^{D,val}(x_{\mathbf{I\!P}},\beta,Q^2) \propto 0.27\beta(1-\beta)\,, \tag{6}$$

In a very narrow limit of $\beta \to 1$ one finds $F_T^{D,val} \propto (1-\beta)^2$, see [8]. With the grain of salt and due reservations for the breaking of the Ingelman-Schlein-Regge factorization, $q\bar{q}$ excitation can be interpreted as DIS on the valence $q\bar{q}$ of the pomeron. For the flavor content and normalization in (6) see [2, 7].

The $q\bar{q}g$ excitation is a driving term of DDIS at $\beta \ll 1$. The crucial finding is a dominance of the leading $\log Q^2$ ordering of sizes [3]

$$Q^{-1} \lesssim r \ll \rho \sim R_c\,, \tag{7}$$

where r and ρ are the $q\bar{q}$ and qg separations. Here $R_c \sim 0.3$fm is the radius of propagation of perturbative gluons in the nonperturbative QCD vacuum and defines still another factorization scale $q^2 \approx \mu_G^2 = R_c^{-2}$, which is universal for all the flavors and for L and T photons. The factor β in $F_T^{D,val}$ derives from the spin $\frac{1}{2}$ of quarks. For the presence of a spin 1 gluon in the $q\bar{q}g$ state of the photon, one finds [2, 3, 7] $F_T^{D,sea}(x_{\mathbf{I\!P}},\beta,Q^2) \sim (1-\beta)^2 G^2(x_{\mathbf{I\!P}}, q_{sea}^2 \approx \mu_G^2)\,,$ which is approximately flat at $\beta \ll 1$ [2, 3]. As such it resembles the sea structure function of hadrons, and excitation of the $q\bar{q}g$ state can be interpreted as DIS on the $q\bar{q}$ sea in the pomeron, which was generated from the valence gluon-gluon component of the pomeron in precisely the same manner as sea in hadrons evolves from gluons. For the wave function of the gg state of the pomeron and $G_{\mathbf{I\!P}}(\beta) \propto (1-\beta)$ see [3]. Because μ_G is different from the quark masses m_f, this brings a still new specimen into the menagerie of "pomeron fluxes" $f_{sea}(x_{\mathbf{I\!P}}) \propto G^2(x_{\mathbf{I\!P}}, q_{sea}^2 \approx \mu_G^2)\,$, for the detailed parameterization of different flux functions see [7, 8, 9]. The normalization g of the sea term in $F_2^D(x_{\mathbf{I\!P}},\beta,Q^2) \propto \beta(1-\beta) + g(1-\beta)^2$ is related to the so-called triple-pomeron coupling [2, 3, 10]. The $\propto (1-\beta)^2$ sea term is non-negotiable, already in 1991 we predicted $g \sim .5$ [2], for slight update see [7], ZEUS [14] gave an important confirmation of our predictions for F^D and for the sea term in particular: $g = 0.34 \pm 0.16$. Predictions for DDIS are parameter free, they use the same gBFKL color dipole cross section which gives a perfect description of the proton structure function [15] and of the vector meson production [16]. There is no momentum sum rule for the pomeron, momentum fractions $\langle\beta_i\rangle$ change with $x_{\mathbf{I\!P}}$. Our prediction [2, 3, 7] for a moderately small $x_{\mathbf{I\!P}}$ is that $\langle\beta_{val}\rangle \sim \langle\beta_{sea}\rangle \sim \langle\beta_{glue}\rangle$.

6 Chameleon exponent n of the $\propto x_{\mathbf{I\!P}}^{-n}$ fits

The exponent n of the popular fit $F_{T,L}^D(x_{\mathbf{I\!P}},\beta,Q^2) \propto x_{\mathbf{I\!P}}^{1-n}$ describes the $x_{\mathbf{I\!P}}$ dependence of the flux functions ϕ_{val}, f_{sea}. We predicted [7, 8] that at HERA, from $x_{\mathbf{I\!P}} \sim 0.1$ down to

$x_{\mathbb{P}} \sim 0.001$, the fluxes for the valence light quark, valence charm and sea components of the pomeron must diverge by the factor $\sim 2-5$! For instance, the abundance of charm in DDIS is predicted to rise from $\approx 3\%$ at $x_{\mathbb{P}} = 0.01$ to $\approx 25\%$ at $x_{\mathbb{P}} = 0.0001$. For this plethora of pomeron fluxes, n must vary with flavor, β, Q^2, k^2, what not, even for the pure pomeron exchange, which is a non-negotiable QCD prediction.

7 Back to the triple-Regge phenomenology?

The recent data on n from ZEUS [17] and H1 [18] are inconclusive and somewhat conflicting. Different selections of DDIS by H1 and ZEUS may pick up different contamination from the secondary reggeon exchanges, in particular at a not so small $x_{\mathbb{P}}$, which is the case at small β. For instance, for the π-exchange $n_\pi \approx -1$ vs. $n_{\mathbb{P}} \sim 1.2-1.3$, the π contamination rises with $x_{\mathbb{P}}$ and is substantial already at $x_{\mathbb{P}} \sim 0.1$ [19]. For the $\rho, \omega, \mathbb{P}'$ exchanges $n_R \approx 0$. Reggeon contributions decrease the observed $n(\beta)$ towards small β precisely the way reported by H1 [18]. Because the DDIS is soft dominated (Section 3), the reggeon contamination must be about the same as in hadronic diffraction [20], i.e., non-negligible even at $x_{\mathbb{P}} \sim 0.05$. Landshoff [21] had made similar observations. The good old triple-Regge phenomenology is called upon! We suggest a simple test of the reggeon contamination: the smaller is Q^2 the smaller are $x_{\mathbb{P}}$ and the weaker must be the depletion of $n(\beta, Q^2)$ towards small β.

8 σ_L/σ_T for diffractive DIS

Compare F_T^D of Eq. (6) with $F_L^{D,val}(x_{\mathbb{P}}, \beta, Q^2) \propto \frac{1}{Q^2}(1-2\beta)^2\beta^3$, which strongly peaks at large β and has a specific zero at $\beta = 0.5$ [6, 9]. Compared to DIS on hadrons, this is an entirely new situation. The photon polarization ϵ_L can readily be varied changing $x_{\mathbb{P}}$. Because the $x_{\mathbb{P}}$ dependence of "pomeron fluxes" is under good control, the predicted [9] dominance of F_L^D at $\beta \gtrsim 0.9$ can easily be tested experimentally. In the sea region of $\beta \ll 1$ we predict [9] $F_L^{D,sea}/F_T^{D,sea} \approx 0.2$, which is the same as for inclusive DIS [15].

9 The Q^2 and β evolution of diffractive DIS and jets at $\beta \ll 1$

The familiar GLDAP evolution derives from the radiation of partons with transverse momenta $R_N^{-2} \lesssim k^2 \lesssim Q^2$. In DDIS instead of fixed R_N^{-2} there emerges the scale (5) which is $\sim Q^2$ at $\beta \to 1$. Furthermore, the interplay of the virtual and real radiative corrections is quite different for inclusive DIS and DDIS [3], which may explain why $F_2^D(x_{\mathbb{P}}, \beta, Q^2)$ at large β refuses to decrease with Q^2 [22, 14], more theoretical work is needed here. The threshold effects in the charm excitation produce [8] a non-negligible rise of large-β F_2^D with Q^2. At last but not the least, F_L^D dominates at large β, which is not the case with the hadrons. The GLDAP analysis of the Q^2 dependence of F_2^D is illegitimate at large β, hasty conclusions from such an analysis of DDIS on $G_{\mathbb{P}}(\beta)$ singular at $\beta \to 1$ must be ignored. The sound

expectations for the β dependence of the valence quark, glue and sea described in Section 5 stay viable.

The situation changes profoundly at $\beta \ll 1$. Here we have a rigorous proof [3] that for the leading logQ^2 ordering of sizes (5) the Q^2 and β evolution of $F_2^D(Q^2, x_{\bf IP}, \beta)$ must be similar to that of the proton structure function, which agrees with the experiment [22, 14, 18]. Finally, for the same ordering of sizes (5) production of the quark-antiquark jets in diffractive excitation of the $q\bar{q}g$ states proceeds via standard fusion of photons with the valence gluons of the pomeron and there is experimental evidence for that [23, 24, 18]. The present MC codes do rely upon the discredited Regge factorization too heavily , though [11].

10 Inclusive-exclusive duality in diffractive DIS

A duality between diffraction into the low mass continuum, $M^2 \lesssim M_o^2 \sim M_V^2$, and exclusive production of vector mesons,

$$\int_0^{M_o^2} dM^2 (d\sigma_{T,L}^D/dM^2) \approx \sigma_{T,L}(\gamma^* \to V)\,, \tag{8}$$

is not a conjecture, but a highly nontrivial result derived from QCD [9]. Recall the QCD results [25, 16] $\sigma_T(\gamma^* \to V) \propto G^2(x, \frac{1}{4}(Q^2 + M_V^2))/(Q^{-2} + M_V^2)^4$ and $\sigma_L/\sigma_T \approx Q^2/M_V^2$. With our results for the large-β behaviour of $F_{T,L}^D(Q^2, x_{\bf IP}, \beta)$, the l.h.s. and r.h.s. of (8) have a perfectly matching Q^2 dependence. It is remarkable how for the $\propto (1-\beta)^2$ decrease of the leading twist F_T^D, the higher twist F_L^D which is finite at large-β, takes over in the duality integral so that $d\sigma_L^D/d\sigma_T^D \approx Q^2/M_V^2$ for the low-mass continuum! Furthermore, in the limit of $M^2 \sim M_V^2$ we have $q_{T,L}^2 \sim \frac{1}{4}(Q^2 + M_V^2)$, which matches perfectly the pQCD scale in the vector meson production [16].

For the **Conclusions** see Section 1.

References:

References

[1] N.N. Nikolaev and B.G. Zakharov, *Z. Phys.* **C49**, 607 (1991)

[2] N.N. Nikolaev and B.G. Zakharov, *Z. Phys.* **C53**, 331 (1992).

[3] N.N.Nikolaev and B.G.Zakharov, *JETP* **78**, 598 (1994); *Z. Phys.* **C64** (1994) 631.

[4] N.N.Nikolaev, B.G.Zakharov and V.R.Zoller, *JETP* **78**, 806 (1996); N.N.Nikolaev and B.G.Zakharov, *Phys. Lett.* **B327**, 157 (1996).

[5] N.N.Nikolaev and B.G.Zakharov, *Phys. Lett.* **B332**, 184 (1996). .

[6] N.N.Nikolaev and B.G.Zakharov, *Phys. Lett.* **B332**, 177 (1994).

[7] M.Genovese, N.Nikolaev and B.Zakharov, *JETP* **81** 625 (1995).

[8] M.Genovese, N.Nikolaev and B.Zakharov, *Phys. Lett.* **B378**, 347 (1996).

[9] M.Genovese, N.Nikolaev and B.Zakharov, *Phys.Lett.* **B280**, 213 (1996).

[10] M.Genovese, N.Nikolaev and B.Zakharov, *JETP* **81**, 633 (1995).

[11] A.Solano, these proceedings.

[12] G.Ingelman and P.Schlein, *Phys. Lett.* **B152**, 256 (1985); A.Donnachie and P.V.Landshoff, *Phys. Lett.* **B191**, 309 (1987); A.Capella et al., *Phys. Lett.* **B343**, 403 (1995); K.Golec-Biernat and J.Kwiecinski, *Phys. Lett.* **B353**, 329 (1995); J.W.Stirling, these proceedings..

[13] J.Bartels, these proceedings.

[14] ZEUS: M.Derrick et al., *Z. Phys.* **C68**, 559 (1995); **C70**, 391 (1996).

[15] N.N.Nikolaev and B.G.Zakharov, *Phys. Lett.* **B327**, 149 (1994).

[16] J.Nemchik, N.N.Nikolaev and B.G.Zakharov, *Phys. Lett.* **B341** 228 (1994). J.Nemchik et al., *Phys. Lett.* **B374**, 199 (1996).

[17] ZEUS: H.Kowalski, these proceedings.

[18] H1: P.Newman, I.Thiessen, S.Tapprogge, these proceedings.

[19] H.Holtmann et al., *Phys. Lett.* **B338**, 363 (1994).

[20] Yu.M.Kazarinov et al.,*Sov. Phys. JETP* **43**, 598 (1976).

[21] P.Landshoff, these proceedings.

[22] H1: T.Ahmed et al., *Phys. Lett.* **B348**, 681 (1995).

[23] ZEUS: M.Derrick et al., *Pys. Lett.* **B346**, 399 (1995).

[24] H1: S.Aid et al., *Z. Phys.* **C70**, 609 (1996).

[25] B.Z.Kopeliovich, J.Nemchik, N.N.Nikolaev and B.G.Zakharov, *Phys. Lett.* **B324**, 469 (1994).